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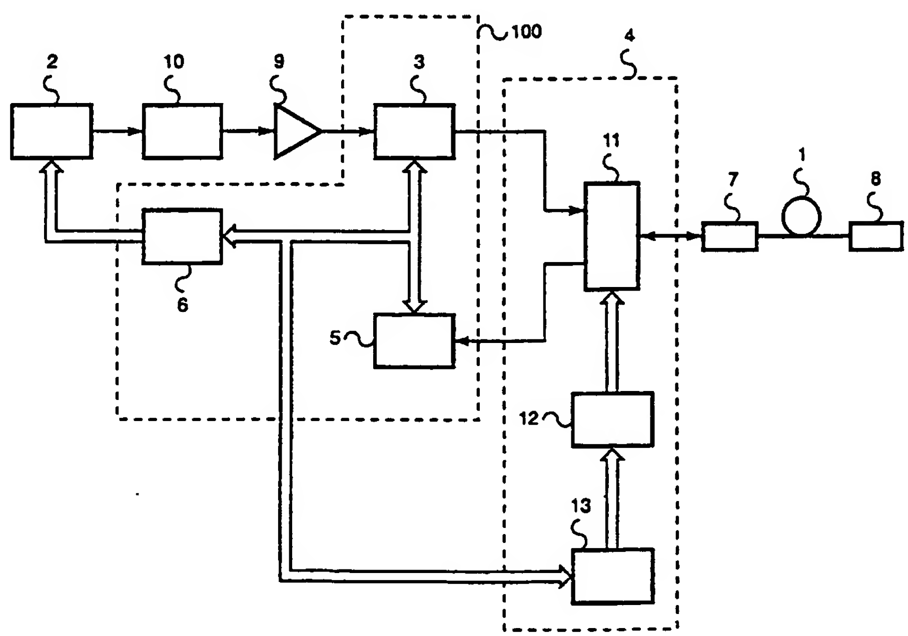
(54) Title: PROCESS AND APPARATUS FOR MEASURING POLARISATION DISPERSION IN OPTICAL FIBRES



(57) Abstract: The process and apparatus to enable measurement of polarisation dispersion of a single-mode optical fibre (1) by launching measurement light at one end of the fibre (1) and analysing polarisation of the light reflected by the other end and collected at such launch end. Optical or electronic masking of light reflected by the near end of the fibre (1) is performed during launch.

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Process and Apparatus for Measuring Polarisation Dispersion in Optical Fibres

This invention relates to the characterisation of optical components and more specifically to a process and an apparatus for measuring polarisation dispersion in single-mode optical fibres.

Polarisation dispersion (commonly known in literature with the acronym PMD from the initials of the English denomination "Polarisation Mode Dispersion") is defined as the differential group delay between two orthogonally polarised modes, which causes digital communication system impulses to widen or analog communication system impulses to distort. This phenomenon is due to fibre manufacturing imperfections (elliptical nucleus and material anisotropy) or to external mechanical stresses (flattening, folding, torsion and the like) that make propagating light divide into two local polarisation modes that propagate at different speeds. Unless properly controlled, this phenomenon can limit the performance of high capacity (10 Gbit/s or more) optical system or even inhibit operation.

Dispersion of the polarisation of the fibres and components with which new high capacity optical networks are manufactured must therefore be accurately measured or characterised in terms of polarisation dispersion in view of the installation of new systems in the event of existing systems being enlarged.

A certain number of techniques for measuring polarisation dispersion have been the subject of international regulations. In particular, Recommendation ITU-T G.650 proposes using analysis of the Jones matrix self-values, the Poincaré sphere and the fixed polarizer and interferometry methods. All these techniques enable the measurement of the differential delay of the average group, namely of the magnitude that best characterises polarisation dispersion of optical fibres and its influence on transmission systems.

All the measurement methods mentioned above present the drawback of requiring access to both fibre ends. These techniques in fact analyse the signal transmitted by the optical signal under test and thus require the use of one end for launching the test optical signal and the other end for measuring the variations induced by the fibre on the signal polarisation features. This limitation is clearly irrelevant for laboratory or factory measurements on optical fibres and cables wound on coils (where the two ends are at a maximum distance of a few metres) or on optical fibre components, but makes polarisation dispersion measurement difficult on the fibres making up the transmission lines of already installed optical systems where the opposite ends of the optical fibres can be placed at a distance of many tens of kilometres. In these cases, at least two operators connected to one another are required; one for checking the optical source and the other for checking the polarisation analyser, or connection must be made between the two instruments for measurement control transmission. Both solutions are complicated and costly.

Techniques for measuring polarisation dispersion based on the analysis of the signal reflected from the far end of the optical fibre have already been proposed, requiring access to one end only of the optical fibre being measured, with remarkable time and resources savings.

In particular, the article "Single-End Polarisation Mode Dispersion Measurement Using Backreflected Spectra Through A Linear Polarizer" in the Journal of Lightwave Technology, Volume 17, Number 10 of October 1999, pages 1835 - 1842, by the Inventors, describes an apparatus whose light issued by a tuneable source is made first to pass through a polarisation control device that gives it the required polarisation status and is then launched onto the fibre by means of a polarisation-insensitive directional coupler. This unit receives the light emitted by the far end of the fibre and sends it to a polarisation analyser connected to a processing device that

performs the processing necessary to achieve polarisation dispersion.

Another polarisation dispersion analysis apparatus based on light reflected from the fibre far end is described in WO-A-9836256 by A. Galtarossa. This apparatus is however based on the principles of time-dependent optical reflectometry and is conceived to measure polarisation dispersion spatial distribution rather than its average value along the whole length of the connection.

When performing measurements accessing only one end of the fibre, light reflected at the launch end must be eliminated as it would add to the light reflected by the far end and alter measurements. The article by the inventors mentioned above suggested using an angle connector for this purpose, to launch the light. The use of an angle connector is a solution suitable for laboratory testing but not for field measurements as it is not commonly applied in field systems.

The purpose of the invention is to supply a process and an apparatus for measuring polarisation dispersion based on backreflected light analysis, which can be easily used on already installed systems.

The process covered by the invention provides for sending to a nearby end of the fibre measurement light at different wavelengths with a plurality of polarity conditions for each wavelength, collection of the corresponding light reflected by the remote end of the fibre and leaving through the said near end, and polarisation analysis and processing of the polarisation analysis results. It is characterised by the fact that during transmission of measurement light in the fibre, the reflected light from such near end is masked to prevent it from reaching the facilities performing the polarisation analysis and overlapping such reflected light from the far end.

The apparatus for achieving the process consists of:

- a wavelength tuneable source to subsequently generate different wavelengths included within a preset wavelength interval;
- polarisation control means to supply a sequence of polarisation conditions to the light emitted by the source for each of such wavelengths;
- means for launching in a near end of the fibre the light from the polarisation control means and collecting the light reflected by a remote end of the fibre itself and leaving such near end;
- means for analysing polarisation, receiving light collected by the launch and collection means; and

- processing and control means to perform the processing required for obtaining the value of polarisation dispersion from the information supplied by the polarisation analysis means and to check the polarisation analysis means and the polarization control means,

and is characterised by the fact that measurement light launch and backreflected light collection means include means for masking light reflected by the near end of the fibre during launch to prevent it from overlapping with light reflected by the remote end of the fibre in the polarisation analysis means.

For further clarification, reference is made to the enclosed drawings, where:

- figure 1 is the basic diagram of an apparatus for measuring polarisation dispersion of an optical fibre starting from its backreflected light;
- figure 2 is the diagram of an initial form of implementation of the apparatus according to the invention with optical masking of the signals backreflected by the nearby connector;
- figures 3 to 5 are diagrams of some variants to figure 2;
- figure 6 is the diagram of a second form of implementation of the apparatus according to the invention with electrical masking of the signals backreflected by the nearby connector;
- figure 7 is the diagram of a variant to figure 6:

The single line arrows of the figures indicate the itinerary of optical signals (achieved by means of optical fibre sections) and the double line arrows indicate the itinerary of electrical signals. Similar components are indicated with the same references in all figures.

With reference to figure 1, an apparatus for measuring polarisation dispersion of an optical fibre 1 starting from the light backreflected by the same fibre includes:

- a wavelength tuneable light source, i.e. a laser 2 to generate a light whose wavelength is made to change stepwise in a preset wavelength interval;
- a polarisation control device 3 or polarisation state generator, which gives the light emitted by laser 2 the polarisation states required for the measurement in question, in particular three polarisation states at 0°, 45° and 90°, for each of the different wavelengths;
- a device 4 for sending the fibre 1 the light leaving polarisation states generator 3 and collecting the light reflected at the remote end of the fibre; device 4 is

represented here as a simple optical coupler with two unidirectional ports for transmitted light input and reflected light output respectively and a bi-directional port for connection to the fibre;

- a polarimeter 5 that receives backreflected light from the coupler device 4 and analyses its polarisation state; and
- a processor 6 that operates as a system monitoring device by controlling wavelength selection and timing the various measurement stages, besides processing the data supplied by polarimeter 5.

Note that even though elements 3, 5 and 6 of the functional diagram drawing are represented as separate as they actually perform distinct functions, backreflected light measurement instruments are available commercially that include all such blocks. An example is the PROFILE PAT 9000 instrument manufactured by the Company PROFILE GmbH of Munich, Germany. Dotted line block 100 is the measurement instrument real and proper.

An apparatus of this type essentially corresponds to the one illustrated in the article by the inventors. The processing operations to be completed for measuring polarisation dispersion are described in the article mentioned and need not be reported in detail here. Suffice it to recall that device 6 calculates average group differential delay of the backreflected field in accordance with one of the standard techniques mentioned above and immediately calculates from such value the average group delay of the transmitted field, which is the parameter to be actually identified, since a simple proportion exists between the two values, as described in the article.

The drawing also illustrates connectors 7, 8 placed at fibre 1 nearby end (launch) and remote end (reflection). Measurement of backreflection-based dispersion requires that the contribution to reflected power by Fresnel reflection at the remote end 8 be prevalent over the contribution by Rayleigh backreflection. The necessary conditions for obtaining this, are also discussed in detail in the article by the inventors.

As mentioned above, correct polarisation dispersion measurement requires that polarimeter 5 be prevented from receiving light reflected by the fibre 1 nearby end, that is to say by connector 7. The invention provides an apparatus capable of achieving this condition compatibly with the need to perform field measurements.

Figures 2 to 5 represent some forms of implementation of the invention based on a polarimeter 5 optical isolation during light measurement launch into the fibre and therefore on optical masking of the light reflected by the remote fibre end. These solutions enable use of commercially available instruments and require using optical components external to the apparatus itself.

Figure 2 shows that an optical amplifier 9 and a depolariser 10 are inserted between laser 2 and polarisation state generator 3. Amplifier 9 obviously has the purpose of guaranteeing enough power for the measurement. Depolariser 10 is required because optical amplifier 9 in polarisation behaves differently at different wavelengths and could therefore make generator 3 produce polarisation states with different power at different wavelengths.

Connection device 4 consists of an acoustic-optical switch 11 suitable to alternately connect fibre 1 to polarization state generator 3 or polarimeter 5 to prevent polarimeter 5 from being reached by the light backreflected by connector 7. Switch 11 is piloted conventionally by a radio frequency signal generator 12 with the purpose of keeping switch 11 in one of its two positions (such as the position in which switch 11 connects fibre 1 to polarisation state generator 3, for instance). The radio frequency signal generator is in its turn controlled by an impulse generator 13 that generates impulses at a repeat frequency and having a duration selected based on fibre length and the features of the polarimeter used. In particular, impulses will be present in the periods during which measurement light must be launched to the fibre and absent when light backreflected by remote connector 8 must be collected with the polarimeter. Radio frequency generator 12 is deactivated during the periods of absence of impulses and switch 11 connects fibre 1 to polarimeter 5, while the latter is optically isolated during measurement light launch.

Bearing in mind that impulse frequency and duration are related to the length of the specific fibre 1 to be characterised, impulse generator 13 will be advantageously slaved to control computer 6 where fibre information is input to enable proper processing of the backreflected signal.

In the variant of figure 3, use is still made of acoustic-optical switch 11 to isolate polarimeter 5 from fibre 1 during measurement light launch. Impulse generator 13 also modulates laser 2 with all/nothing modulation to send an impulsive signal to fibre 1 instead of continuous light. The switch thus operates in a synchronous mode

by generating measurement impulses. In this arrangement, the optical amplifier should preferably not be connected to the itinerary of laser 2 output impulses as the amplifier is known to be capable of producing excess power peaks. The impulsive signal is also sufficiently powerful by itself for the required measurement dynamics.

Figure 4 shows a variant of the device of figure 3. Instead of alternately connecting the nearby fibre end to polarisation state generator 3 or to polarimeter 5, all/nothing modulation of light transmitted to the polarimeter is used and cancellation takes place at light measurement transmission to fibre 1. Polarisation state generator 3 and polarimeter 5 are respectively connected to an input and an output port of a three-way circulator 14 provided with a bi-directional input-output port connected to fibre 1. An acoustic-optical modulator 15 is placed between circulator output port 14 and polarimeter 5 suitable to introduce all/nothing modulation into the signals that cross it. Similarly to switch 11 of figure 3, modulator 15 is piloted by radio frequency signal generator 12 controlled by impulse generator 13 that modulates laser 2.

In the diagram of figure 5 related to a solution where continuous light is sent to the fibre, use is still made of a three-way circulator 14 connected to polarisation state generator 3, fibre 1 and polarimeter 5, as in the diagram of figure 4. In this case, light backreflected by connector 7 is masked by a couple of acoustic-optical modulators 15A, 15B respectively located between polarisation state generator 3 and circulator 14 input and between the latter output and polarimeter 5 input. The two modulators are piloted by their respective radio frequency signal generators 12A, 12B controlled by impulse generator 130. The two modulations must obviously be complementary.

Figures 6 and 7 show two possible solutions to mask backreflected light with electronic instruments. A solution of this type presents economic advantages over the use of optical components. The functions of connection device 4 of figure 1 are partially performed in these implementations by incorporating circuits in instrument 100. In both these solutions, use is made of impulsive light obtained by modulating laser 2 with an impulse generator similar to the one described in the previous forms of implementation.

In particular, figure 6, which essentially corresponds to figure 4, still uses optical circulator 14 to connect fibre 1 to measurement instrument 100. Impulse generator

131 modulating laser 2 acts on the electronic circuits of polarimeter 5 to disable it during measurement light launch. This function is represented in the diagram by the presence of an electronic switch 16, between circulator 14 output port and polarimeter 5, controlled by the same laser modulation impulses.

Figure 7 shows a synchronous detector 17 between circulator 14 output and polarimeter 5 input, piloted by an impulse generator 132 to give detector 17 the necessary reference signal at the same frequency as the impulses controlling laser 2. Technicians are aware that synchronous detector 17 can distinguish between signals reflected at fibre remote end 8 and those reflected at nearby end 7, based on the phase relationship with the reference signal, by only sending the former to polarimeter 5.

The above description was obviously only given as a non-limiting example and variants and modifications are possible without leaving the protection scope of the invention. With suitable methods well known to technicians, optical amplifier 9 can also be used for an impulsive source or continuous light can be used even in implementations where masking is with electronic circuits. Furthermore, the means used for masking the light reflected by the nearby end can consist of equivalent devices. It will for instance be possible to use optical switches instead of acoustic-optical components, as long as they are produced with a technology guaranteeing sufficiently fast response (as an example, fibre 1 connections may need to be switched at an interval of between 100 and 500 ns), or to use electro-optical modulators, electro-mechanical modulators and the like.

Claims

1. Process for measuring polarisation dispersion of a single-mode optical fibre (1), whereby measurement light is sent to a nearby end (7) at various different wavelengths and different polarisation states for each wavelength, the corresponding light reflected by the fibre remote end (8) and leaving such nearby end (7) is collected and analysed with reference to polarisation and the results of such polarisation analysis are processed, characterised by the fact that when measurement light is sent to fibre (1) the light reflected by such nearby end (7) is masked to prevent it from reaching means (5) performing such polarisation analysis and overlapping such light reflected by the remote end.

2. Process as in claim 1, characterised by the fact that masking of light reflected by fibre (1) nearby end (7) is achieved optically.

3. Process as in claim 2, characterised by the fact that such optical masking is achieved by alternately connecting the fibre nearby end to polarisation control means (3) imposing polarisation states required for the measurement light or to the polarisation analysis means (5).

4. Process as in claim 3, characterised by the fact that the operation of alternately connecting fibre (1) nearby end (7) to the polarisation control means (3) or to the polarisation analysis means (5) is obtained by optical or acoustic-optical switching controlled by a sequence of impulses, the frequency and duration of which are related to the length of the fibre under review.

5. Process as in claim 2, characterised by the fact that such nearby fibre end (7) is connected permanently both to polarisation control means (3) and to the polarisation analysis means (5) and that such masking is performed by all/nothing modulation of at least the light from such nearby end (7).

6. Process as in claim 5, characterised by the fact that such optical masking is performed by all/nothing modulation both of the measurement light launched

into fibre (1) and of light from fibre (1), modulation of light from the fibre being complementary to the modulation of light launched into the fibre.

7. Process as in claim 5 or 6, characterised by the fact that such all/nothing modulation is selected from acoustic-optical, electrical-optical, electromechanical or optical modulations and is controlled by a sequence of impulses of frequency and duration related to the length of the fibre under review.

8. Process as in any of the previous claims, characterised by the fact that such measurement light is continuous and that an optical amplification of light generated by a source (2) is performed, after depolarisation.

9. Process as in any of claims 2, 4, 6, 7, characterised by the fact that such measurement light is impulsive light, the generation of which is controlled by such sequence of impulses.

10. Process as in claim 1, characterised by the fact that masking of light reflected by fibre (1) nearby end (7) is performed electronically.

11. Process as in claim 10, characterised by the fact that such masking includes the operation of disabling polarisation analysis means (5) during time intervals corresponding to the launch of measurement light into fibre (1).

12. Process as in claim 11, characterised by the fact that such periodic disabling is controlled by a sequence of impulses of frequency and duration related to the length of the fibre under review.

13. Process as in claim 12, characterised by the fact that such sequence of impulses is also supplied to the source (2) of measurement light to generate impulsive light.

14. Process as in any of the claims from 10 to 12, characterised by the fact that such measurement light is continuous and by the fact that optical amplification

is performed on the light generated by source (2), preceded by light depolarisation.

15. Process as in claim 10, characterised by the fact that such masking includes synchronous detection of light transmitted to polarisation analysis means (5) on command by a reference signal having the same frequency as that of a sequence of impulses of frequency and duration related to the length of the fibre under review, said impulses controlling the generation of an impulsive measurement light by measurement light source (2).

16. Apparatus for measuring polarisation dispersion of a single-mode optical fibre (1), inclusive of:
    - a wavelength tuneable light source (2) to sequentially generate a light of different wavelengths included in a preset interval of wavelengths;
    - polarisation control means (3) to sequentially impose of different polarisation states to the light emitted by source (2) for each of such wavelengths;
    - means (4) for launching the light emitted by polarisation control means (3) into a fibre (1) nearby end (7) and for collecting the light reflected by a remote end (8) of the fibre, coming from such nearby end (7);
    - polarisation analysis means (5) receiving the reflected light from launch and collection means (4); and
    - control and processing means (6) to perform the processing operations required to obtain the value of polarisation dispersion from the information supplied by the polarisation analysis means (5) and to control the source (2) and the polarisation control and analysis means (4, 5),

    characterised by the fact that the measurement light launch and backreflected light collection means (4) include means (11, 12, 13; 12, 13, 15; 12A, 15A, 12B, 15B, 130; 16, 131; 17, 132) for masking light reflected by fibre (1) nearby end (7) during launch, to prevent its overlapping fibre (1) remote end (8) reflected light in polarisation analysis means (5).

17. Apparatus as in claim 16, characterised by the fact that such masking means

(11, 12, 13; 12, 13, 15; 12A, 15A, 12B, 15B, 130) are optical type means.

18. Apparatus as in claim 17, characterised by the fact that such optical masking means include a switch (11) for alternately connecting fibre (1) nearby end (7) to polarisation control means (3) or to polarisation analysis means (5).

19. Apparatus as in claim 18, characterised by the fact that such switch (11) is controlled by an impulse generator (13) generating a sequence of impulses the frequency and the duration of which is related to at least the length of the fibre under review.

20. Apparatus as in claim 19, characterised by the fact that such switch (11) is an acoustic-optical switch piloted by a radio frequency signal generator (12) and that such impulse generator (13) controls such radio frequency signal generator (12).

21. Apparatus as in claim 19, characterised by the fact that such switch (11) is an optical switch.

22. Apparatus as in claim 17, characterised by the fact that such launch and collection means (4) include an optical circulator (14) provided with an input port connected to polarisation control means (4), an input-output port connected to fibre (1) nearby end (7) and an output port connected to such polarisation analysis means (5) and by the fact that such optical masking means include modulation means (15; 15A, 15B) connected at least between circulator (14) output port and polarisation analysis means (5) for all/nothing modulation of light transmitted to such polarisation analysis means (5).

23. Apparatus as in claim 22, characterised by the fact that such modulation means (15; 15A, 15B) are controlled by an impulse generator (13; 130) generating a sequence of impulses of frequency and duration related to the length of the fibre under review.

24. Apparatus as in claim 22 or 23, characterised by the fact that such modulation means (15; 15A, 15B) include a first and a second modulator (15A, 15B) respectively connected between circulator (14) input port and polarisation control means (4) and between circulator (14) output port and polarisation analysis means (5) for all/nothing modulation of light sent to fibre (1) and all/nothing modulation, complementary to the former, of the light sent to such polarisation analysis means (5).

25. Apparatus as in any of the claims from 22 to 24, characterised by the fact that such modulation means (15; 15A, 15B) are selected among optical, acoustic-optical, electro-optical or electromechanical modulation means.

26. Apparatus as in claim 25 if referred to claim 23, characterised by the fact that such modulation means (15; 15A, 15B) are acoustic-optical modulation means piloted by a radio frequency signal generator (12, 12A, 12B) and that such impulse generator (13) controls such radio frequency signal generator (12, 12A, 12B).

27. Apparatus as in any of the claims from 16 to 26, characterised by the fact that such source (2) is a source of continuous light and by the fact that optical light means (9) of light leaving the source preceded by depolarisation means (10) are provided between source (2) and polarisation control means (3).

28. Apparatus as in any of the claims from 16 to 26, characterised by the fact that such source (2) is a source of impulsive light, controlled by an impulse generator (13).

29. Apparatus as in claim 16, characterised by the fact that such masking means (16, 131; 17, 132) are electronic type means.

30. Apparatus as in claim 29, characterised by the fact that such masking means (16, 131) include means for disabling polarisation analysis means (5) at time intervals during which measurement light is launched to fibre (1).

31. Apparatus as in claim 30, characterised by the fact that such means disabling the polarisation analysis disabling means (5) include an electronic shutter (16) controlled by an impulse generator (131) the output pulses of which have a frequency and duration related at least to the length of the fibre under review.

32. Apparatus as in claim 31, characterised by the fact that such impulse generator (131) is connected to such source (2) to control the emission of measurement light impulses.

33. Apparatus as in any of the claims from 29 to 31, characterised by the fact that such source (2) is a source of continuous light and by the fact that optical amplification means (9) are provided between source (2) and polarisation control means (3) for light leaving the source preceded by depolarisation means (10).

34. Apparatus as in claim 29, characterised by the fact that such source (2) is a source of impulsive light controlled by an impulse generator (132) the output pulses of which have a frequency and duration related to the length of the fibre under review, and that such masking means (17, 132) include means (17) for detection of light sent to polarisation analysis means (5) synchronous with the emission of measurement light impulses.

35. Apparatus as in claim 34, characterised by the fact that synchronous detection means (17) are connected to such generator by a sequence of impulses (132) suitable to generate and supply the synchronous detection means (17) with a reference signal (132) which has the same frequency as that of the impulses of such sequence.

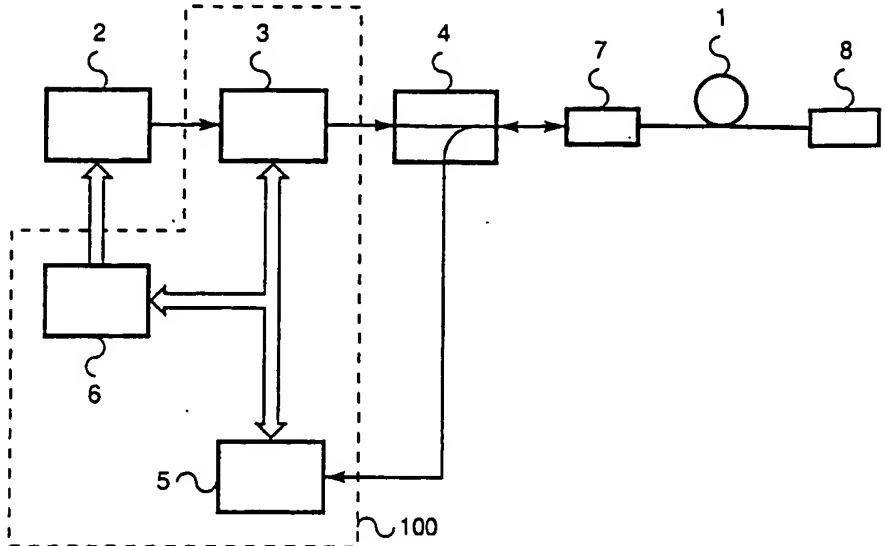

Fig. 1

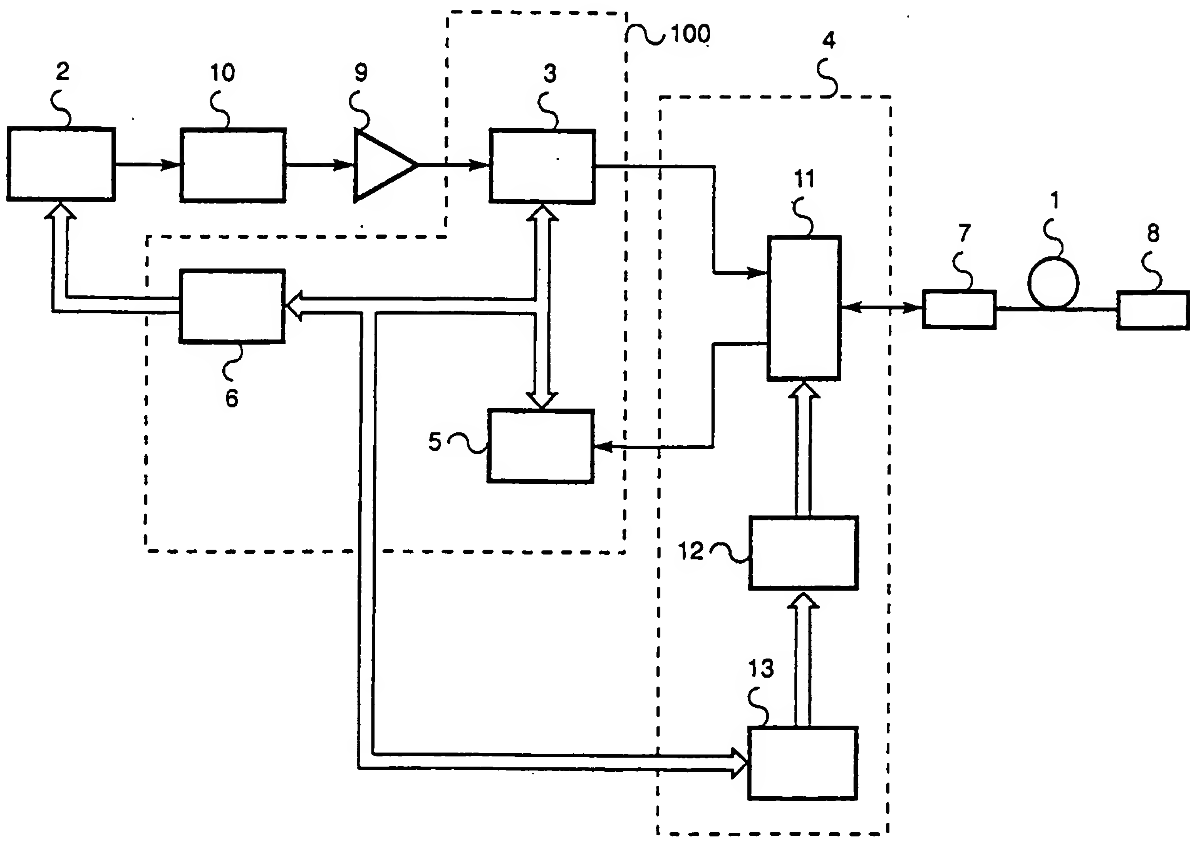

Fig. 2

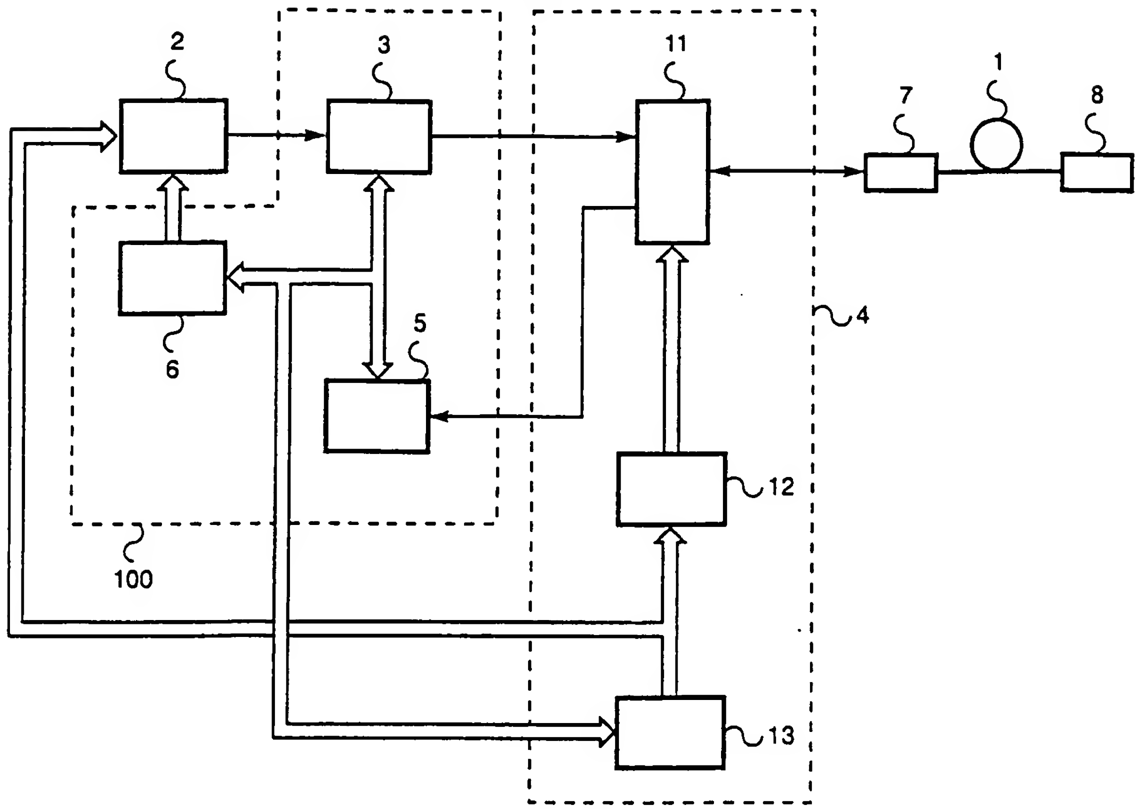

Fig. 3

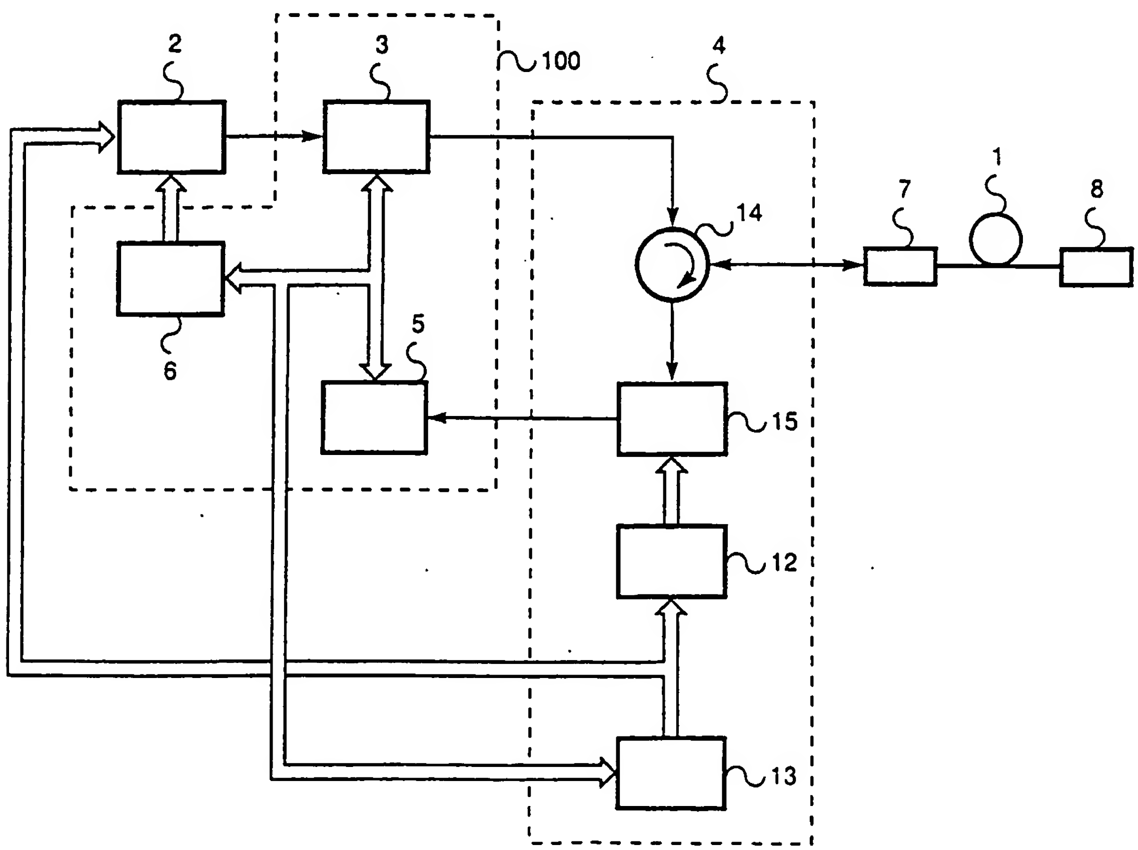

Fig. 4

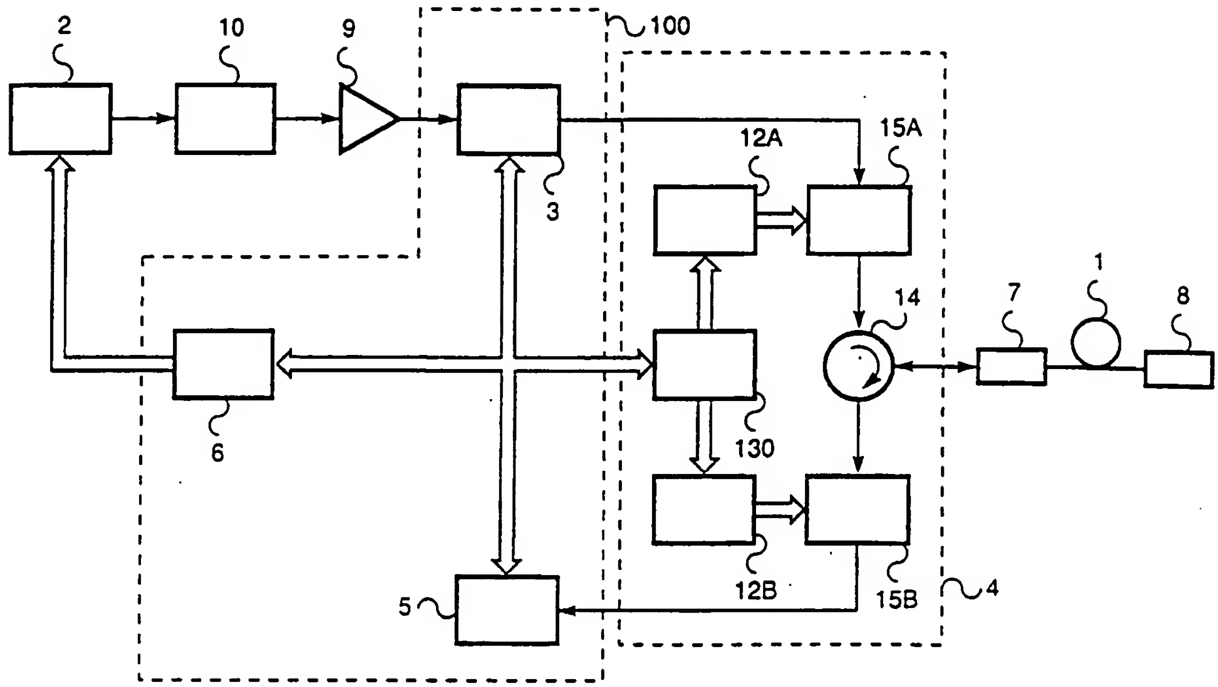

Fig. 5

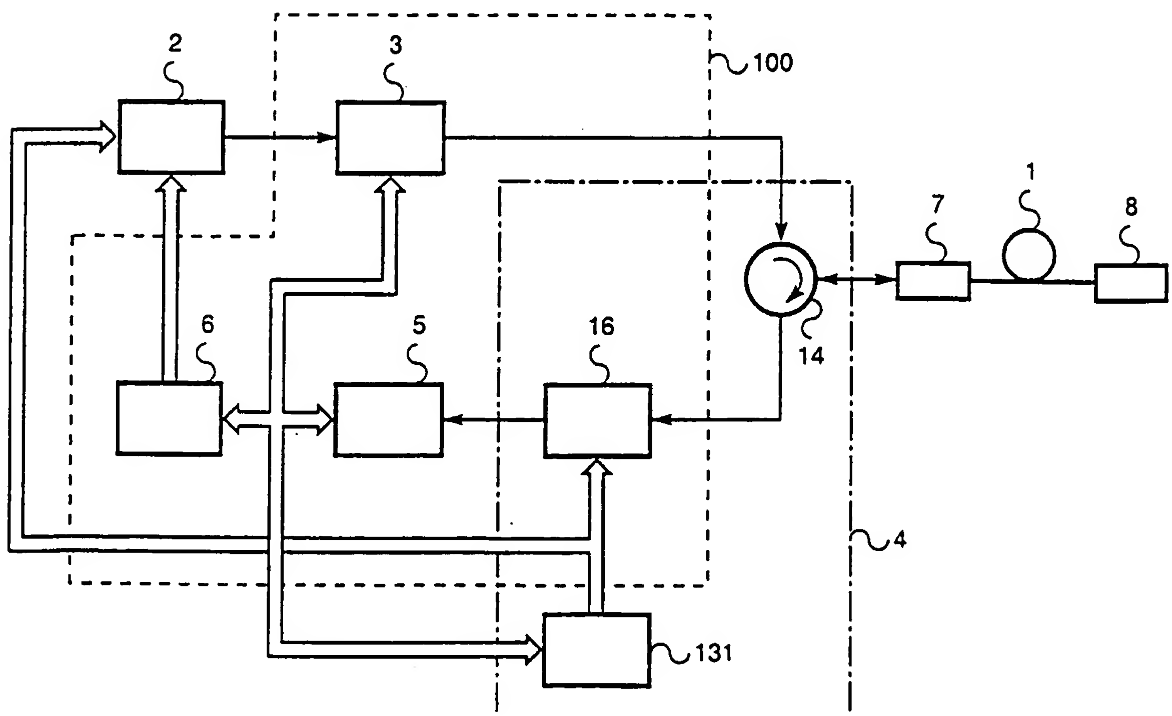

Fig. 6

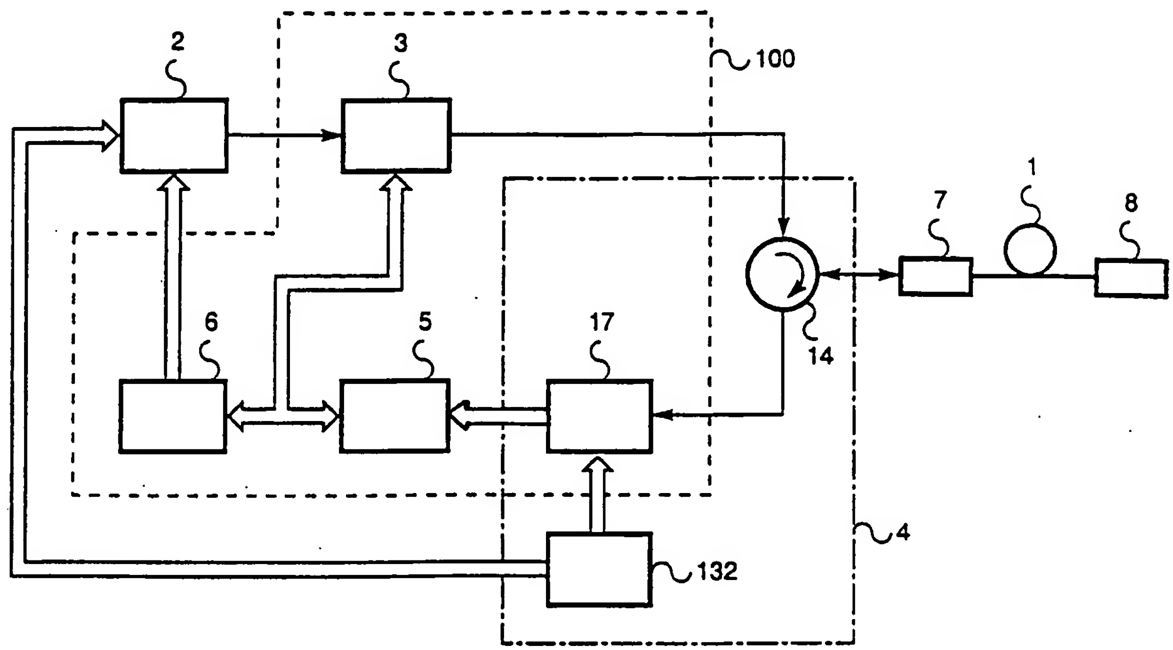

Fig. 7

INTERNATIONAL SEARCH REPORT

Inte ional Application No
PCT/EP 00/11305

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B10/18 H04B10/08 G01M11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GALTAROSSA A ET AL: "Single-end polarization mode dispersion measurement using backreflected spectra through a linear polarizer" JOURNAL OF LIGHTWAVE TECHNOLOGY, OCT. 1999, IEEE, USA, vol. 17, no. 10, pages 1835-1842, XP000984134 ISSN: 0733-8724 cited in the application	1,2,16, 17,27
Y	page 1835, left-hand column, paragraph 3 -right-hand column, paragraph 2 page 1839, left-hand column, last paragraph -right-hand column, paragraph 1 figure 3	3,4, 8-11,18, 19,21, 28-30

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2001	05/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Carrasco Comes, N

2

Inte onal Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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